Plant biology in space

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EDITORIAL

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In August 2012, more than 60 invited scientists and representatives of space agencies from different continents, nationalities and disciplines attended the international workshop on 'Plant Biology Research in Space', held at the University of Freiburg, Germany. This workshop – jointly organised by the French and German space agencies, CNES and DLR – was embedded as satellite symposium into the Plant Biology Congress 2012, held by FESPB and EPSO, the two leading European organisations involved in plant research. Using this setup, it was also hoped that scientists from the so-called non-space community would be attracted to the specific topic of plant biology in space. This idea proved very successful: more than 600 participants attended – for instance – the plenary lecture from Stan Roux on 'New insights in plant biology gained from space research'.

The 'Plant Biology in Space' workshop was one in a series of symposia, initiated in 1995 by the International Space Life Sciences Working Group (ISLSWG) of leading space agencies from around the globe. The main goal of these workshops is to review progress in a specific research area and to identify open questions for future space and accompanying ground-based research, thereby stimulating international cooperation. Interestingly, the first plant biology workshop was also held in Germany, in 1996. Since then, more than 20 workshops have been organised by ISLSWG, ranging from molecular, cell, plant and radiation biology via muscle, bone and neurovestibular physiology, to behaviour and performance of humans in space. The results of these workshops have been published in high-ranking scientific journals, often as supplements or special issues.

The ISLSWG itself was established in 1989; at that time, representatives of the leading life sciences programmes of six space agencies agreed to form a special working group with two overall goals, namely, to strengthen space research by increased coordination and cooperation as well as to enhance the exchange of knowledge and information. The six space agencies were NASA (United States), ESA (Europe), CNES (France), CSA (Canada), DLR (Germany) and JAXA (Japan). Since then, also the space agencies of Italy (ASI) and of Ukraine (NSAU) joined the group. Through the establishment of ISLSWG and the development and implementation of its strategic plan, cooperation among space agencies in the field of life sciences, which had happened for more than 20 years on a more case-by-case basis, was placed on official solid ground.

Since its foundation more than 20 years ago, the ISLSWG has achieved a lot: joint Spacelab/Shuttle missions were realized; in terms of human physiology research, also bed rest and isolation studies were jointly conducted. The ISLSWG coordinated the development of experiment facilities, *e.g.* for the International Space Station (ISS). Also, the use of the ISS for life science research was – and still is – coordinated with great efficiency. Up to now there have been six ILSRAs (International Space Life Sciences Research Announcements). Experiment proposals have been recruited for ISS research also in plant biology, jointly peer reviewed by international review teams and selected for implementation on ISS. Moreover, the seventh ILSRA is currently open for proposal submission until end of March 2014.

This special supplement of Plant Biology presents the outcome of the Freiburg Plant Biology workshop, focusing on the fundamental role that gravity plays in plant growth, development and orientation. The reader will find ten scientific reviews and 13 research papers from a group of experts, most of them involved in space biology research. The supplement starts with an acute view of accomplishments achieved and recommendations for future research for plant biology in space. Here, also an attempt is undertaken to analyse whether and how the recommendations of the 1996 ISLSWG Plant Biology workshop have been followed and which of the scientific questions – prioritised at that time – have been answered in the meantime (Ruyters & Braun 2014). Also as a kind of recommendation for future work, Kiss (2014) proposed exciting perspectives in the context of Mars and Moon exploration.

The contributions of the supplement focus basically on three different topics: plant growth and physiology, with special attention given to gravitropism; plant molecular biology; and the role of plants in bioregenerative life support systems (BLSS). The gravitropic response pathway as such can be divided into sequential steps: (i) perception of the signal; (ii) signal transduction leading to the redistribution of auxin, and finally; (iii) the gravitropic curvature response.

Kordyum (2014) provides a short overview on the effects of real and simulated microgravity on cell components, including statolith positioning, mitochondria, tubulin and the endoplasmic reticulum. Although significant progress has been made in identifying stimulus-responsive elements, the nature of the sensors remains elusive. Iida *et al.* (2014) summarise their work on a group of mechanosensitive channels in *Arabidopsis*, named MCA1 and MCA2, and their putative role in gravity sensing in *Arabidopsis*. Tatsumi *et al.* (2014) describe recent progress in mechanosensitive channels controlled by the actin cytoskeleton. The involvement of the actin cytoskeleton in gravity perception is further investigated in plant cells. Using imaging tools, Grolig *et al.* (2014) report on the role of actin in organelle movement in the sporangiophore of the zygomycete *Phycomyces blakesleeanus*.

Auxin transport is an essential component of the signalling pathway of root and shoot gravitropism. Progress in this area is highlighted in the paper from Geisler *et al.* (2014), describing approaches used for the analysis of auxin redistribution and quantification of auxin fluxes. The report of Ueda *et al.* (2014) complements this view by examining the relationship between polar auxin transport and graviresponse in the context of microgravity. A comprehensive analysis of global gene expression of floral buds reveals that hypergravity substantially changes expression of genes involved in the biosynthesis of phytohormones such as abscisic acid and auxin (Tamaoki *et al.* 2014).

The effects of gravity on plant developmental processes are reviewed in Herranz & Medina (2014). They studied microgravity effects on cell proliferation within the root meristem. Using parabolic flights, the studies of Hausmann *et al.* (2014) and Aubry-Hivet *et al.* (2014) reported changes in gene and protein expression in *A. thaliana* cells and fundamental changes in metabolic pathways, respectively. The interesting report from Hoson *et al.* (2014) supports the concept that microtubules are important players in mediating gravity resistance in *Arabidopsis*. Furthermore, Nakashima *et al.* (2014) provide evidence that actin might also be an important modulator of root growth in space, while Scherer & Pietrzyk (2014) report on root coiling in Arabidopsis.

Although in most of the research described *A. thaliana* is used as model species, some other model organisms are also discussed. Galland (2014) and Göttig & Galland (2014) use the sporangiophore of *P. blakesleeanus* to investigate fungal graviperception and graviresponses. Analyses of spores of the fern *Ceratopteris richardii* reveal the gravity-affected expression of a PM-type Ca^{2+} ATPase (Bushart *et al.* 2014). Scherer & Quader (2014) show a transient increase of endocytosis in tobacco pollen tubes in microgravity. Finally, using *Euglena gracilis*, Nasir *et al.* (2014) demonstrate changes in expression of stress-related genes in microgravity, confirming results from higher plants.

Space experiments are certainly the best method for studying the effects of changed gravity conditions on plant developmental processes; however, also the considerable impact of radiation on organisms must be considered when going into space. Arena *et al.* (2014) demonstrate in *Phaseolus vulgaris* how leaf development and growth biochemically respond to ionising radiation. Similar results obtained by De Micco *et al.* (2014b) show the effect of X-ray irradiation on the anatomy of mature *P. vulgaris* leaves.

Although we are aware that seed-to-seed cycles can be achieved, the review from De Micco *et al.* (2014a) highlights some negative effects of space conditions on plant growth and the consequences for crop productivity. Generally supporting this view, Paradiso *et al.* (2014) provide a state-of-the-art summary of soybean cultivation in the bioregenerative ecosystem MELISSA (Micro-Ecological Life-Support System Alternative). These papers underline the crucial importance of the development of new technologies for BLSS and the importance of analysing all growth and reproductive phases of the plant life cycle in order to optimise utilisation of resources in plant-based BLSS.

We feel confident that the contributions in the present supplement will provide interesting information on plant biology research in space and useful guidelines for scientists around the world for future research in this fascinating field. As has been convincingly shown in the past, results of these activities are not only important in the context of space research, but also contribute to answering fundamental questions in the area of plant biology, *e.g.* on plant growth and development as well as on signal transduction in plants.

Finally, the editors and the space agency representatives thank the authors for their contributions, the many dedicated reviewers for helping to improve and strengthen the papers published in this supplement, as well as the workshop session chairs and Prof. Volkmann (University of Bonn) for providing valuable inputs for the analysis of accomplishments and future recommendations for research in plant biology in space.

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